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EVALUATION OF MIGRATION AND SURVIVAL OF JUVENILE STEELHEAD FOLLOWING TRANSPORTATION

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EXECUTIVE SUMMARY

* Following release, steelhead in the lower Columbia River migrated 134-143 kilometers downstream to the monitoring station in 31.9-89.9 hours. Mean swimming velocity was 3.3 kilometers per hour (kph) and ranged from 1.5 - 4.5 kph.

* Migration speeds of barged and ROR steelhead were not significantly different in three of the four releases. ROR fish migration speed was not different between releases; barged fish migration speed was higher during one release than the other three releases.

* Migration patterns of barged and ROR fish in the estuary were similar. Movement of radio-tagged juvenile steelhead in the lower estuary was influenced by tidal stage, with individuals moving downstream quickly on an outgoing tide and either moving downstream slowly, holding, or moving slightly upstream on an incoming tide.

* Large portions of both barged and ROR steelhead successfully migrated to the estuary: 70% - 90% of barged fish and 40% - 100% of the ROR fish were observed at, or downstream of, the fixed monitoring station at river kilometer 89.4. For all releases, there was no significant difference between barged and ROR groups in proportion of fish reaching the estuary.

* Of all radio-tagged steelhead, 14 % (5% - 25% for each release) of barged fish and 5% (0% - 20% for each release) of ROR fish were observed in colonies of piscivorous birds on Rice Island or East Sand Island by aircraft or boats and were considered mortalities. Avian predation did not differ between barged and ROR fish. Mean mortality for pooled barged and ROR steelhead was 10% (5% - 20% for each release).

* There was no significant difference in length between radio-tagged barged and ROR fish in three of the four releases. Length was significantly different between releases for ROR fish, but not for the barged fish. The barged fish had a significantly higher condition factor than ROR fish on three of the four releases. Condition factor was different for both barged and

ROR fish between dates.

* ROR fish had significantly higher levels of Gill Na^+/K^+ ATPase than barged fish on the first release, but not on the second and third releases. There was no significant difference in ATPase levels between releases for ROR fish, though there was for barged fish.

* ROR fish had significantly higher plasma cortisol levels than barged fish on two of the three releases. This suggests either higher stress levels for in-river migrants or a difference in holding or collection techniques between fish types. There was a strong relationship between mean cortisol levels and number of smolts arriving at Bonneville Dam (smolt counts) for ROR fish.

* Prevalence of bacterial kidney disease (BKD) was low throughout the season, with 100% of the fish having no or low detectable levels of infection. There were no differences in BKD levels between fish types within a release or between releases within a type.

* Saltwater preference experiments indicated no significant difference between barged or ROR fish in the percent of fish selecting saltwater at 60 minutes or 120 minutes after the start of the experiment.

* The feed intake experiment indicated that feed intake (% of body weight per feeding) did not differ significantly between barged and ROR fish on any given day. Both types of fish fed well once exposed to saltwater. Fish in both groups appeared to osmoregulate well based on plasma sodium, plasma potassium, and muscle moisture levels. Only one mortality in both types of fish occurred during the experiment, suggesting no differences in mortality after 14 days in saltwater.

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OBJECTIVES

The goal of this study is to obtain information that will allow us to make recommendations concerning how the fish transportation program may be managed to minimize the severe loss of fish in the estuary. Specific objectives of the 2000 project were as followed:

1) Document post-transport behavior of juvenile passage delays of transported steelhead to inriver migrating steelhead into and through the estuarine environment.

2) Determine and correlate fish condition to migration behavior through the estuary and saltwater interface to river condition and other indicators of estuarine productivity.

3) Establish the relationship between fish behavior in the estuarine and near-shore oceanic environment and the physiological indicators of fish quality. Examine the relationship between the developmental stage of the transported steelhead to migration delays in the estuary and survival to ocean entry.

INTRODUCTION

The success of transportation is determined by the performance of the transported fish following release. Post-release performance of fish is a function of fish quality at release, which is itself determined by both fish condition at collection and the effect of transportation. Fish condition at collection may be extremely important in affecting success of the program. Condition of fish when they reach the dam is extremely variable in terms of their general quality and health. There is not only variation over the course of the run, but also between individuals collected at any one time. We suspect that this variation in fish quality is reflected in the ability of juvenile salmonids to migrate down the lower Columbia River and successfully pass through the estuary.

Prior research of radio-tagged juvenile spring chinook salmon has found that 10-30% were taken by piscivorous birds in the Columbia River estuary (Schreck et al., submitted). If this percentage is similar for steelhead, than the total number of Columbia River smolts taken by birds near the mouth of the river could have a significant impact on salmonid populations. It is not known what factors determine the vulnerability of migrating juvenile salmonids to bird predators, although fish behavior in the estuary clearly has the potential to affect the likelihood of being eaten. For example, those individuals who swim higher in the water column, or linger in areas containing many birds, may be more at risk. A number of factors relating to fish health and development (smoltification) have been shown to influence the behavior and survival of juvenile salmonids.

We postulate that the quality of migrants reaching the lower Columbia River (either by barge or in-river migration) relates to subsequent behavior and avoidance of predation. Fish quality may particularly relate to delays in seawater entry in the Columbia estuary. Such delays could result in more predation by increasing the amount of time the migrants spend in the freshwater lens, where the fish are exposed to large concentrations of birds and may be easier to catch due to the relatively shallow nature of the freshwater lens. Smoltification, disease, and stress status may all influence the amount of time a fish might be ○trapped○ in the freshwater lens. Prior research on the Columbia River (Schreck and Stahl, 1998) has suggested that the delay in seawater entry may be related to fish remaining in the surface layer of fresh water as long as possible, not to how much time is spent in the estuary. Although physiological condition influences behavior, the exact relationship between fish quality indices and behavior is not always intuitive. From the saltwater preference experiments, it has been demonstrated that seawater entry behavior of fish may not coincide with their physiological readiness. Once the linkages between fish quality and behavior are understood, the opportunity exists to manage the migration of juvenile salmonids through the Columbia Basin hydropower system to maximize downstream survival. Hence, how fish are ○delivered○ to the lower river could affect their ability or propensity to migrate; therefore, delivery systems (i.e., barging, passage of dams, or spill regulation) are tactics that may play various roles in affecting ocean entry success at various times throughout a run.

During the 2000 field season, information was collected concerning detailed migration behavior of juvenile hatchery steelhead in the Columbia River and estuarine environments. Increased understanding of smolt behavior in the estuary is needed to determine what may be done to minimize avian predation. Radio-tracking of different types of fish, barged and run-of-the-river (ROR), throughout the outmigration season was the primary objective. Radio-tags that transmit depth information were used in addition to standard tags, to better understand vertical distribution of fish in relation to salinity and avian predators. The observed behavior and survival of these fish was compared to physiological condition of other fish sampled at dams at the same time as fish were tagged. Finally, laboratory experiments were performed looking at how fish type (barged and ROR), time of the season, smoltification levels, and BKD levels might affect the fish's preference for saltwater. Experiments were also completed on feed intake and physiological adaptation in saltwater between the two types of fish.

METHODS

1) Document post-transport behavior of juvenile passage delays of transported steelhead to inriver migrating steelhead into and through the estuarine environment.

The migration behavior of yearling hatchery steelhead in the lower Columbia River downstream of Bonneville Dam was documented using radiotelemetry. We examined migration of both barged steelhead, collected while in transport, and ROR fish, collected at Bonneville Dam Second Powerhouse Juvenile Fish Facility (B2J). Radio transmitters were purchased from Advanced Telemetry Systems (ATS - Isanti, Minnesota) and operated on the 148-149 megahertz bandwidth. Standard transmitters and depth transmitters were used. Standard tags weighed approximately 1.2 g in air and depth tags weighed 1.9 g. Both types of tags were designed to transmit continuously for a minimum of 7 days. To reduce the number of frequencies to be scanned during tracking, two tags were placed on each frequency and were distinguished by different beeping rates (approximately 40 or 60 beeps per minute). Before use, all tags were checked for proper functioning following a 24 h immersion in water.

Radio-tagged fish were released on four dates in May and early June of 2000. Up to 18 fish were tagged with standard transmitters and 2 fish were tagged with depth transmitters for each type of fish on each of the four dates over the 2000 outmigration. A detailed description of the dates, numbers, and characteristics of radio-tagged fish is contained in Table 1. Barged fish were collected on the fish transportation barges between John Day Dam and Bonneville Dam. Fish were netted from holding tanks that contained smolts collected at Lower Granite Dam Juvenile Fish Facility. Only hatchery steelhead, identified by an adipose fin clip, were collected. Individuals were anesthetized in 50 mg/l tricane methanesulfonate (MS222) buffered with 100 mg/l $NaHCO_3$, after which the transmitter was surgically implanted into the body cavity using modified techniques from Moore et. al. (1990). Sutures were used to close the incision, antibiotics were applied, and Stress Coat® (Aquarium Pharmaceuticals, Inc.) was used to replace the loss of a naturally secreted coating. Following tagging, fish were placed in 125 liter live wells secured in the barge holds, and allowed to recover. On the first release, 10 fish were placed in a livewell. Four antennas became tangled and had to be cut shorter to free the fish; however, all of these fish were subsequently detected downstream. After this, only 3-4 fish were placed in each livewell. After fish recovered (approximately 30 minutes), they were released from livewells into the barge holding tanks. An observer stayed on board after the barge passed Bonneville Dam to verify that all tags were transmitting and to record the release time and location.

Run-of-the-river yearling hatchery steelhead to be radio-tagged were obtained at Bonneville Dam (B2J) as part of the daily sample collected over a 24 hour period by Pacific States Marine Fisheries Commission (PSMFC) personnel for smolt monitoring purposes. Timing of these releases was designed to coincide with peak passage of Snake River juvenile salmonids past Bonneville Dam, so that we could obtain the highest proportion of Snake River fish for tagging (Figures 1A and 1B). On the dates of tagging, hatchery steelhead were passing the dam, but the exact origin of any given individual implanted with a radio-tag is unknown. After collection by PSMFC personnel, fish were placed in 125 liter livewells for subsequent tagging (approximately 2-5 h later). The tagging procedure was identical to that used for barged fish. At release, fish were placed back into the bypass system. In an effort to standardize the arrival time of barged and ROR migrants in the estuary (which might influence risk of predation from birds), releases at Bonneville Dam were made after the transport barge carrying the paired release group of radio-tagged fish had passed B2J. The two groups were released within 20 minutes of each other. Details of the releases are described in Table 1.

Following release, radio-tagged individuals were monitored from an aircraft. Location data were collected daily for a period of 2-3 days starting on the first or second day following release, depending on weather conditions. The aircraft used for tracking was equipped with one ATS Challenger 2000 and one Lotek SRX_400 (for depth tags) radio receiver; each was connected to antennas mounted on both wing struts. Flights were conducted at an altitude of 153 m with an air speed of approximately 160-177 kilometers per hour. Once a radio signal was heard, the plane circled until its precise location could be determined. The effective distance a tag could be detected ranged from approximately 0.4 to 1.6 kilometers. Due to the extreme width of the river in the estuary the search pattern was a series of east/west transects spaced at 1.2 kilometer intervals. The transects were used from the mouth of the river up to river kilometer 48.3.

The progress of radio-tagged individuals was also recorded at a fixed monitoring station located upstream of river kilometer 89.4, near the community of Bunker Hill, Washington. This location is approximately 144 kilometers downstream of Bonneville Dam. In this area, the river is relatively narrow and the shipping channel abuts a series of cliffs on the Washington shoreline. Tracking data suggests that juvenile salmonids are often located in or near the shipping channel, and thus can be expected to pass near the Washington shore (and the monitoring station) at this site (Schreck et al., 1997; Schreck and Stahl, 1998). Two 6-element Yagi antennas were placed on a mast 3 m above the ground and approximately 31 m above river level. Antennas were pointed directly to the far side of the river and were each connected to a Lotek receiver. The same frequencies were scanned by both receivers, but scanning was off-set so that scan time for all frequencies was reduced. The monitoring station was staffed 24 hours a day during periods of tagged fish migration.

Detailed behavior of individual migrants in the estuary was examined. Either one or two 6 m Alumaweld boats (depending on available personnel), each equipped with one 4-element Yagi antenna and a Lotek receiver, were used to continuously monitor the behavior of individuals as they migrated down the estuary. Tracking began approximately one hour after the peak of high tide, usually in the morning. A boat would traverse the estuary monitoring both barged and ROR fish frequencies. When the first signal was heard, the operators would stop scanning and only track that specific frequency. Once tracking began, the boat was kept as close to the fish as possible. At approximately 15 minute intervals, the location of the boat was located and recorded on a GPS (Global Positioning System; Garmin GPSMAP 230) unit. A fish was tracked until it moved into water too shallow for the boat, the signal was lost and could not be reacquired after set search limits, or other factors, such as weather, made continued tracking unsafe.

Water quality data were collected during tracking in order to determine the immediate environmental conditions associated with the fish. A YSI model 85 DO/Salinity meter was used to measure water salinity and temperature. Readings were taken once per hour unless current, wave conditions, or possible loss of the fish being tracked precluded stopping for measurements. Data was collected at three depths for each location: the surface, half of the total depth, and near the bottom (taken from depth finders on the boats).

In order to get better estimates of mortality due to avian predators, one datalogging station was set up on Rice Island to monitor for radiotags at the island's Caspian tern colony. Two stations were set up on East Sand Island; one station monitored the Caspian tern colony on the eastern side of the island and one station monitored the double-crested cormorant colony on the western side. These stations were placed to confirm and supplement the data collected by the aircraft over the islands. All stations consisted of a 6-element Yagi antenna mounted on a pole, 2 m above the ground. The antennae were plugged into a Lotek receiver, powered by a 12 volt deep cycle battery, located in a lockbox at the base of the pole. These stations were set up prior to arrival of fish in the estuary and data was downloaded after each release. Due to inconsistencies and random frequency interference, no data from these three stations was usable in 2000.

2) Determine and correlate fish condition to migration behavior through the estuary and saltwater interface to river condition and other indicators of estuarine productivity.

Hatchery yearling steelhead were collected for physiological sampling on three of the four releases in which radio-tagged groups were released (see Table 1). This allowed the health condition for each cohort of radio-tagged fish to be documented and the differences in the response to transportation, collection, and handling, over the migration season to be measured. Health and smoltification indicators were compared to migration behavior (primarily migration speed) and survival of the corresponding radio-tagged groups in an effort to determine if these indicators are predictive of post-release performance.

Barged fish were obtained from the barge by pulling a lift net in the same compartments from which radio-tagged fish were taken. ROR juvenile steelhead were collected at Bonneville Dam, B2J, from PSMFC personnel when ROR radio-tagged fish were collected. The dates, numbers, and types of fish collected for these tests are given in Table 1.

For physiological sampling, fish were immediately killed with an overdose of anesthetic (200 mg/l MS222 buffered with 500 mg/l NaHCO3). The lengths, weights, presence of fin clips, and abnormalities (i.e., scale loss, puncture marks) were recorded for each fish. The caudal peduncle was severed and whole blood collected in ammonium-heparinized capillary tubes. Blood was centrifuged, after which plasma was removed, and immediately frozen on dry ice. Plasma was later stored at -80° C. Gill filaments were collected, placed into a buffer solution, and frozen on dry ice (Zaugg, 1982). Whole kidneys were removed and frozen as well.

Plasma cortisol concentration was measured as an index of stress. Plasma cortisol is a widely accepted measure of the primary (neuroendocrine) response to stress (Mazeaud et al., 1977). Thawed plasma samples were assayed for cortisol using a radioimmunoassay (Foster and Dunn, 1974) as modified for use with salmonid plasma (Redding et al., 1984). Smoltification was estimated by measuring gill Na^{+}/K^{+} ATPase; which is an accepted index of this transformation (Hoar, 1988; Lysfjord and Staurnes, 1998). Gill samples were analyzed at the USGS-BRD Northwest Science Center, Columbia River Field Station (Cook, WA). Kidneys were analyzed for the presence of bacterial kidney disease (BKD) by the Oregon Department of Fish and Wildlife (526 Nash Hall, Corvallis, OR). Presence and severity of infection was measured using a modified technique from Pascho et al. (1991).

3) Establish the relationship between fish behavior in the estuarine and near-shore oceanic environment and the physiological indicators of fish quality. Examine the relationship between the developmental stage of the transported steelhead to migration delays in the estuary and survival to ocean entry.

To establish the relationship between fish behavior in the estuarine and near-shore oceanic environment and the physiological indicators of fish quality, two separate experiments were designed. One examined the fish's preference for saltwater, comparing behavioral response to salinity with physiological indices. Results were related to the behavior of radio-tagged cohorts moving through the estuary and into saltwater. The other experiment measured feed intake and physiological adaptation in seawater.

Saltwater Preference Experiment

A system for testing salinity preference was developed using a vertical salinity gradient. The experimental setup consisted of four 380 l rectangular fiberglass tanks (1.83 x 0.66 x 0.60 m) with acrylic windows in front to view the fish. Tanks were placed in a quite area and were visually isolated by black curtains. Saltwater was prepared (Instant Ocean™, 30 ppt) in separate tanks. At the start of a test, approximately 190 l of saltwater was pumped into the bottom of the observation tanks through perforated PVC pipe. This was done slowly, over approximately a 1 hour period, to establish a vertical salinity gradient. The window of each test tank was marked to show the final dividing line between fresh and saltwater.

Barged fish were collected from the barge at Bonneville Dam, prior to entry into the Bonneville Navigation Lock. ROR fish were collected at B2J in the same manner as described in *Objective 1*. The dates, numbers, and types of fish collected for these tests are given in Table 1. Fish were placed in 125 liter livewells with air pumps and transported to Oregon State University§s Smith Farm Fish Physiology Laboratory. Seven fish were placed in each of four observation tanks and allowed to acclimate for 34.5 - 36.5 hours. During acclimation, flow-through well water at 12.5° C was supplied to the tanks. Two tanks (one of which was a replicate) contained barged fish and two contained ROR fish. Seven fish per tank was near the maximum number that could be tested at once due to their large size and consequent mixing of water occurring from movement. Following acclimation, the position of the fish in the water column was observed and then the saltwater was introduced. The position of each fish was recorded every 10 minutes for 120 minutes, including the 60 minutes of saltwater introduction.

Feed Intake Experiment

The fish used in this experiment were collected in the same manner as in the saltwater preference experiment. The dates, numbers, and types of fish collected for these tests are given in Table 1. Insufficient ROR fish could be obtained in the first day of collection, so the collection was done over two consecutive days. The fish from each day were transported in livewells supplied with oxygen to Oregon State University's Hatfield Marine Science Center in Newport. Transport time was approximately 4 hours. In Newport, fish were transferred into hatchery tanks (1 m wide, water depth 60 cm) supplied with dechlorinated tap-water at 13° C. Two replicated tanks for each type of fish were used, each tank contained either 25 barged fish or 24 ROR fish. On May 5, fresh water was replaced with seawater (13° C, 6.5 – 7.0 l/min, salinity varying between 29.9 and 31.0 ppt).

The fish were fed twice a day by hand (once during weekends) in excess with commercial dry feed (Bio Dry 1000, Bio-Oregon, Warrenton, OR). The feed had previously been ground into powder and repelleted. A small batch of the ground feed was mixed with small lead glass beads (ballotini size 9, Jencons Ltd, Leighton Buzzard, U.K., 1.2% of weight) before repelletising for the estimation of feed intake by X-radiography (Jobling et al., 1993). Known amounts of this labeled feed were then X-rayed and a standard curve for the relationship between numbers of ballotinis (B) and feed's weight (g) were calculated ($g = 0.087 + 0.018 \times B$, $r^2 = 0.97$, $N = 12$).

The fish were fed in excess with the labeled feed approximately 15 min before sampling on day 1, 7, and 14 after saltwater introduction. Eight fish were then netted from each tank and killed by overdose in MS222 (200 mg/l, buffered by $NaHCO_3$). Fish were weighed (to 0.1 g) and measured for total length (to 1 mm). Blood was withdrawn from the caudal vessel into a lithium heparinized vacutainer, plasma was separated and analyzed later for sodium and potassium concentrations (Nova 1 Na^+, K^+ analyzer by Nova biomedical, Waltham, MA). A small piece of dorsal musculature was taken for determination of muscle water content. Afterwards, fish were X-rayed, number of beads were counted, and the amount of feed eaten by each individual was estimated. The liver was also separated and weighed (to 0.01 g) for the estimation of hepatosomatic index, HSI = liver weight / fish weight x 100. Condition factor, K, was calculated according to the formula: $K = \text{weight (g)} / \text{length (mm)}^3 \times 10^5$.

Statistical Analyses

Statistical analyses were performed on the following groups of fish:

1. "telemetry" fish - barged and ROR radio-tagged juvenile steelhead (Objective 1)
2. "physiology" fish - barged, and ROR juvenile steelhead collected for physiological sampling (Objective 2)
3. saltwater preference fish – barged and ROR juvenile steelhead collected for saltwater preference assessment (Objective 3), and
4. Feed intake fish – barged and ROR juvenile steelhead collected for feed intake assessment (Objective 3)

Telemetry and physiology fish measures were compared both within fish types (i.e., barged and ROR fish) between different releases and within different releases between fish types. A single-factor ANOVA was used for most comparisons. If there were only two levels in the comparison, this test was a t-test. If there were less than 15 fish in any comparison, a Kruskal-Wallis comparison of medians (nonparametric ranks) was used. For these tests, if a significant factor effect was found, differences between levels were assessed by Fisher's least significant difference (LSD) procedure at the 95% level. For comparisons of proportions without any replication within levels (i.e., BKD presence in physiology), a χ^2 test was used for tests with greater than two levels and a Fisher's Exact Test was used for comparisons with two levels. For comparison of mortality due to avian predators (i.e., survival) and our recapture efficiency of telemetry fish, a logistic regression was used to analyze the proportion data. The test used for the logistic regression was the χ^2 statistic, unless the data were over- or underdispersed (determined if $P_D < \alpha_{\text{one-tailed}} = 0.025$, where P_D is the P-value for over- or underdispersion), in which case the standard errors were adjusted and the more conservative F statistic was used.

Comparisons for the saltwater preference experiments were made using a multifactor ANOVA with date and type of fish as factors, these proportion data were arcsine transformed before analysis (though not presentation); the level of BKD infection within these experiments was compared with Fisher's Exact test. The data for the feed intake experiment were compared between types within a date using a nested ANOVA, tank is nested within the type of fish.

RESULTS AND DISCUSSION

1) Document post-transport behavior of juvenile passage delays of transported steelhead to inriver migrating steelhead into and through the estuarine environment.

Following release, steelhead in the lower Columbia River migrated 134-143 kilometers downstream to the monitoring station in 31.9 - 89.9 hours. The total distance individuals traveled over time can be seen in Figure 2. The speed in kilometers per hour (kph) which all individuals migrated from their release location near Bonneville Dam to the fixed monitoring station can be seen in Figure 3A. Mean swimming velocity (Figure 3B) was 3.3 kph and ranged from 1.5 - 4.5 kph. There was a significant difference in migration speeds of barged and ROR steelhead in the first release (p=0.0433, ANOVA) but not in the other three releases (5/15, p=0.2923; 5/25, p=0.6800; 6/4, p=0.8052; ANOVA). The speed was not significantly different between the releases of ROR fish (p=0.2849, ANOVA), but was for barged fish (p=0.0040, ANOVA) with the second release having higher speeds than the other three releases. There was not a relationship between migration speed and Bonneville Dam outflow on the release date for barged or ROR fish (Figure 4; p=0.7988, R^2 =0.0405; p=0.0989, R^2 =0.8120; respectively, linear regression). There was a relationship between speed and outflow in previous studies (Schreck and Stahl, 1998); however, the relationship may not have existed for steelhead due to the narrow range of flows during the field season.

Lengths of the two types of radio-tagged fish did not differ significantly in three of the four releases (Figure 5A; 5/5, p=0.2241; 5/25, p=0.1511; 6/4, p=0.2573; ANOVA), however, there was a difference in the second release (p=0.0344, ANOVA) where ROR fish were larger. The length was significantly different between dates for ROR fish (p=0.0120, ANOVA); the first release was different than the second release, yet both the first and second were not different than the third and fourth release. The length of barged fish was not significantly different between releases (p=0.4021, ANOVA). To determine if the radio-tagged fish were biased from the general population due to tag:body weight constraints of tagging, fish sampled for physiological analysis were compared to radio-tagged fish on each of the sampling dates; barged fish (5/5, p=0.7813; 5/15, p=0.1087; 5/25, p=0.2114; ANOVA) and ROR fish (5/5, p=0.2386; 5/15, p=0.8698; 5/25, p=0.4547; ANOVA) were not significantly different. The length of the fish was not related to migration speed for either barged (p=0.9879, R^2 =0.0001, linear regression) or ROR types (p=0.4727, R^2=0.2780). The radio-tagged barged fish had a significantly higher condition factor (K = weight (g) / length $(mm)^3 \times 10^5$) than ROR fish on three of the four releases (5/5, p=0.0258; 5/15, p=0.0007; 6/4, p=0.0074; ANOVA); the third release was not different between the two types (p=0.4788, ANOVA) which can be seen in Figure 5B. The condition factor changed between dates for both barged and ROR fish (p=0.0002, p=0.0102, respectively, ANOVA). There was no significant relationship between condition factor and migration speed for both barged (p=0.7074, R^2 =0.0026) and ROR fish (p=0.4449, R^2 =0.0143, linear regression). Again, to determine if radio-tagged fish were biased from the general population, fish sampled for physiological analysis were compared to radio-tagged fish on each of the sampling dates; barged fish were not significantly different (5/5, p=0.2610; 5/15, p=0.8430; 5/25, p=0.0726; ANOVA), however, the ROR fish were on the first release (p=0.0275, ANOVA) but not on the other two releases (5/15, p=0.4657; 5/25, p=0.2287), this is possibly due to the small sample size (n=5) of physiology fish on that date.

Large portions in each release of both barged and ROR steelhead successfully migrated to the estuary: 70% - 90% of radio-tagged barged fish and 40% - 100% of ROR fish were observed at, or downstream of, the fixed monitoring station at river kilometer 89.4 (Figure 6A). The overall proportion of fish reaching the estuary was not significantly different between barged and ROR types (p=0.0645, logistic regression) or between releases (p=0.4106). Radio-tagged fish that were never heard accounted for 5% - 15% of barged fish and 0% - 60% of ROR fish. It is unknown why these tags were unheard, since all tags were known to be functioning immediately before release, this must be the result of: (1) fish that were dead on release and sank out of radio range, (2) fish that were taken by predators after release and whose remains were deposited out of radio range, (3) individuals that migrated successfully but went undetected. Regardless of the reason, certain individuals were never observed. It was assumed that all tags were inside fish, transmitting radio signals, and could be detected by the radio receivers. If this assumption is false, then the true sample size of observable radio-tagged fish is reduced and the relative proportion of fish reaching the estuary is higher than reported.

Of all radio-tagged steelhead, 14% (5% - 25% for each release) of barged fish and 5% (0% - 20% for each release) of ROR fish were observed in colonies of piscivorous birds on Rice Island or East Sand Island by aircraft or boats and were considered mortalities. Avian predation did not differ between barged and ROR fish ($p=0.1092$, logistic regression) or between release dates ($p=0.1766$, logistic regression). Mean mortality for pooled barged and ROR steelhead was 10% (5% - 20% for each release). Distribution of mortalities between the two islands is given in Figure 6B. Of the fish released, only one was heard in the vicinity of the bird colonies on Rice Island; this is different from past studies that show much higher percentages of mortalities from the bird colonies on this island (Schreck and Stahl, 1998; Schreck et al., submitted).

At this time, it is not known what influences the level of predation on migrating salmonids in the estuary, but such factors must fall into one of two general categories: either from conditions that influence fishing pressure from birds or phenomena that change the vulnerability of salmonid migrants to predation. The fishing pressure exerted by piscivorous birds is the result of conditions such as population size and availability of alternate prey. Vulnerability of salmonid migrants could be increased by delay in seawater entry (increasing the exposure time to high concentrations of predators in the estuary), swimming higher in the water column, or other behavior that causes them to be more accessible to birds. There was no observable relationship between travel time to the monitoring station and predation; there was no difference in the speed of fish that were eaten versus not eaten ($p=0.6714$, ANOVA). This can also be seen on Figure 2, where the fish that were eventually eaten by birds have no obvious difference in their travel time (i.e. the slowest fish aren't always the ones that are eaten). This might suggest that whatever factors influence travel time are not necessarily related to predation risk in the estuary. Conversely, travel time of migrants could conceivably influence survival in the estuary by determining the time of arrival of fish in areas where birds forage. If migrants were to reach the lower estuary on an outgoing tide during hours of darkness, they may traverse many of the areas of highest predation pressure when birds are not foraging.

Migration routes of radio-tagged yearling steelhead observed from aircraft and by boats (Figure 7) fell into three general patterns based on two points of divergent routes. Fish made one ○decision○ slightly upriver from Rice Island; some stayed within the main shipping channel south of the island, and others followed the old shipping channel north of the island (○North Channel○). Those that were in the North Channel stayed in the northern part of the estuary (Washington side) until they reached the ocean (migration route 1). Those that remained in the shipping channel had another point of divergence near Tongue Point. Again, some stayed in the shipping channel all the way to the ocean (migration route 2); however, many crossed from the Oregon to the Washington side between Tongue Point and the Astoria Bridge and entered the ocean from the northern side of the estuary (migration route 3). These large-scale migration patterns are visible in Figures 7A. The clusters of points on Rice and East Sand Islands represent transmitters heard on the islands and are assumed to be fish consumed by avian predators. No differences in large-scale migration patterns are evident between barged (Figure 7B) and the ROR (Figure 7C) radio-tagged fish.

Generally, fish tracking began near Rice Island one hour after the peak of high tide (outgoing tide) when the fish were moving relatively quickly. During slack tide (arbitrarily defined as one half hour before and one half hour after the peak of a tide) the fish still moved quickly and after the peak of low tide (incoming tide) the fish either moved slowly downstream, held their position or moved slightly upstream. Figure 8A depicts these movement patterns for two of the steelhead tracked, a standardized time was used in this figure since the fish were tracked on different days and the peak of low tide occurred at different times. Figure 8B shows the average speed and range of all tracked fish in the estuary during different tidal stages. There was a significant difference between the speeds of the fish at these different stages (p=0.0035, ANOVA). The time it would take for a fish to migrate from river kilometer 48.3 to the ocean is was estimated. A fish could travel approximately 6 h on an outgoing tide, move slightly downstream ($\approx$ 3.6 km) for 6 h on an incoming tide, again travel for 6 h on an outgoing tide, move slightly downstream again on an incoming tide, then make it to the ocean on the next outgoing tide; the total estimated time would be 24.9 hours. This means it took between 2-3 tidal cycles (a cycle being defined as the peak of high tide to the peak of high tide) for a fish to move from the upper end of the estuary to the ocean. Since the speed of the ROR fish was correlated with river flows, the number of tidal cycles to reach the ocean would vary depending on flows. As additional data to support this theory, no live fish were detected in the estuary on consecutive days.

Data collected from depth tags was examined. All depth data can be viewed in Table 2. The data collected from the plane was not accurate, readings indicated that fish were above the water surface or at a depth that was not possible. This could be due from the altitude of the plane or the speed at which it was flying, not allowing a "fix" on the tag signal. Only one of the depth tagged fish was tracked in the estuary with a boat. Six fish tracked in boats had standard tags and were followed only because they were located first. The depth of the individual with the depth tag as it moved through the estuary can be seen in Figure 9; the reason that the fish is below the bottom at one point is because the channel depth changed quickly in this area making it impossible to precisely measure depth where the fish was located. Of all reliable data (see Table 2), the mean fish depth was 3.35 m (± 0.326 SE). These data, along with the fact that terns only feed in the top meter of the water column, suggests that most of the outmigrating steelhead smolts remain near the surface.

A saltwater ○wedge○ existed in the estuary judged from the water quality data taken by boats as tracking occurred. Higher salinities existed near the bottom of the estuary, while lower salinity fresh water flowed over the saline water due to density gradients. Because few fish were tracked into areas that had a stratified salinity profile, the data are not graphically presented.

2) Determine and correlate fish condition to migration behavior through the estuary and saltwater interface to river condition and other indicators of estuarine productivity.

Plasma cortisol levels of barged and ROR yearling steelhead were compared over the course of the outmigration season. ROR fish had significantly higher cortisol levels than barged fish on the first and second release (Figure 10A; p=0.0049, p=0.0000; respectively, ANOVA). On the third release there was no significant difference between the two types (p=0.1799, ANOVA). The cortisol levels were significantly different between dates for ROR fish (p=0.0028, ANOVA); the third release being lower than the other two releases. The cortisol levels were not different between dates for barged fish (p=0.3442, ANOVA). These elevated cortisol levels in ROR fish on the first and second release could suggest higher stress levels during those periods; however, this stress may be due to the collection and handling method at B2J. Cortisol levels were compared to certain factors to determine whether a relationship existed. There was a strong relationship between the mean cortisol levels and number of smolts arriving at Bonneville Dam (smolt counts) for the ROR fish (p=0.0187, R^2=0.9991, linear regression). Cortisol levels were also compared to fish with 10% or more scale loss. Individual cortisol levels were not significantly different between fish with scale loss and those without scale loss for ROR fish (p=0.3721, ANOVA). Barged fish were not analyzed since none had ≥ 10% scale loss. There was a significant difference between the amount of scale loss and type of fish; more of ROR had ≥ 10% scale loss than barged fish (p=0.0144, type and date as factors, logistic regression).

Gill Na^+/K^+ ATPase activity levels of barged and ROR yearling steelhead were compared. The ROR fish had significantly higher levels of ATPase than barged fish on the first release (Figure 10B; p=0.0385, ANOVA) but there was no difference on the second and third releases (p=0.9479, p=0.2404, respectively, ANOVA). There was a difference between releases for barged fish (p=0.0200, ANOVA), with the second release having higher values than the other two releases. There was no significant difference in ATPase activity levels between the releases of ROR fish (p=0.1800, ANOVA). There was no significant relationship between ATPase and length, weight, or condition factor (p=0.1669, R^2=0.0351; p=0.1167, R^2=0.0449; p=0.7551, R^2=0.0018; respectively; linear regression). One interpretation of greater ATPase levels in the first release could be that they were more smolted. Another eventuality is that the two groups are not comprised of the same stocks of fish.

Prevalence of bacterial kidney disease was low throughout the season, with 100% of the fish having no or low detectable levels of infection (Figure 11). When the proportion of fish with zero level of infection was compared, there was no difference between type of fish within a release (5/5, p=0.6223; 5/15, p=0.6285; 5/25, p=4099; Fisher's Exact test) or between releases within a type (barged, p=0.3916; ROR, p=0.3689; Chi-Square test).

3) Establish the relationship between fish behavior in the estuarine and near-shore oceanic environment and the physiological indicators of fish quality. Examine the relationship between the developmental stage of the transported steelhead to migration delays in the estuary and survival to ocean entry.

Saltwater Preference Experiments

Saltwater preference experiments (two were performed during the season) indicated that there were no significant differences between barged or ROR fish in the percent of fish in saltwater at 60 minutes (Figure 12A; p=1.000) or 120 minutes (Figure 12B; p=0.1754) when using a multifactor ANOVA with date and type as factors. In this analysis, there was also no differences between the two dates at either the 60 minutes (p=0.0858) or at 120 minutes (p=0.9611). There was no difference between length (p=0.9851, ANOVA), weight (p=0.7539), or K (p=0.4323) between the two groups within the first experiment date or the second (p=0.7647, p=0.5073, p=0.2713; respectively; ANOVA). There was no relationship between the percent of fish in saltwater and average length (p=0.1412, R^2=0.3236, linear regression), weight (p=0.2158, R^2=0.2419), or K (p=0.0760, R^2=0.4332) at 60 minutes or at 120 minutes (p=0.6924, R^2=0.0279; p=0.5342, R^2=0.0676; p=0.7316, R^2=0.0211; respectively). There was also no difference in the proportion of fish with no detectable BKD organism between the type of fish within the first experiment date (p=0.2612, Fisher's Exact test) or the second (p=0.7247).

The results of these experiments are very interesting when compared to the gill ATPase levels. There was a significant difference in ATPase levels between the two types in the first release which could possibly be interpreted as a difference in the level of smoltification; however, this was not observed in their preference for saltwater.

Feed Intake Experiment

No growth was observed during the seawater exposure based on the body-weight measurements of eight fish from each tank at day 1, 7, and 14 (Figure 13A); also, no significant differences in size was observed between barged and ROR fish (day 1, $p=0.105$; day 7, $p=0.451$; day 14, $p=0.442$; nested ANOVA). Barged fish had consistently higher Ks than ROR fish (Figure 13B), but this difference was statistically significant ($p = 0.034$, nested ANOVA) only at day 7. The trend of increasing Ks towards the end of the experiment was not statistically significant for barged fish ($p = 0.102$, $R^2 = 0.528$, linear regression), but the ROR trend was significant ($p = 0.007$, $R^2 = 0.869$, linear regression).

Both types of fish appeared to be osmoregulating well based on their plasma sodium values after 1 and 7 days in saltwater (Figure 14A). For an unknown reason, a rise in plasma sodium was observed at day 14 in one replicate for both groups. Sodium levels did not differ between the two types on any given day (day 1, $p=0.677$; day 7, $p=0.703$; day 14, $p=0.940$; nested ANOVA). Plasma potassium values can be seen in Figure 14B; the levels varied little during the course of the experiment and were never significantly different between the fish types (day 1, $p=0.766$; day 7, $p=0.554$; day 14, $p=0.597$; nested ANOVA). Muscle moisture level remained relatively stable and was not significantly different between types (Figure 14C; day 1, $p=0.161$; day 7, $p=0.433$; day 14, $p=0.640$; nested ANOVA). There was also little variation in HSI between the treatments as well as within the treatment during the experiment (Figure 14D).

Both barged and ROR fish steelhead fed extremely well after exposure to seawater. Feed intake (% of body weight per feeding) did not differ significantly between the two types on any given day (day 1, $p=0.221$; day 7, $p=0.560$; day 14, $p=0.242$; nested ANOVA), which can be seen in

Figure 15. When feed intake was calculated by using all the individuals (feeders and non-feeders) there was a large variability between tanks after one day in seawater. At the group level, there was no correlation between feed intake and other variables, such as plasma sodium. Even though there were no differences in feed intake on any given day, the overall feed intake during the experiment was examined using a nested ANOVA. The total feed intake during the experiment was significantly higher in ROR fish than in the barged fish, whether it was calculated using all individuals ($p = 0.035$) or using only feeding individuals ($p = 0.008$); however, both groups were feeding well.

It should also be noted that only one mortality in both types of fish (48-50 total of each type) occurred during the experiment. The total time period that the fish were in saltwater was 14 days. This suggests no differences in mortality after entry into a saltwater environment for the two types of fish.

CONCLUSION

There were very few differences between barged and ROR steelhead. Generally, there was no difference in the migration patterns and speeds of the two types of fish. Steelhead exhibited the same migration patterns in the estuary as previously studied spring chinook salmon (Schreck and Stahl, 1998). The migration speeds are also similar to the chinook when examining releases during similar flow periods, suggesting a passive migration of all salmonids down the Columbia River.

There were some differences indicated in the physiological parameters of the fish. The differences in ATPase was significant between groups on the first release, one interpretation of this could be that there were differences in smoltification levels; however, there were no differences in their migration tendency or their preference for saltwater. This supports the hypothesis that high ATPase levels do not directly correspond to an increase in saltwater adaptability (Lysfjord and Staurnes, 1998) and that ATPase may not be a direct indicators of smoltification, at least on an individual level (Pirhonen and Forsman, 1998). The ROR fish had significantly higher cortisol levels than barged fish on the first and second releases; suggesting higher stress levels during those periods. There was a strong relationship between mean cortisol levels and number of smolts arriving at Bonneville Dam (smolt counts) for ROR fish. Even though there is a strong correlation between the two factors, this does not necessarily mean that it is a causal relationship. Although ROR fish generally had more scale loss, higher cortisol levels, and lower condition factors, their performance in the estuary was not different than barged fish; however, it is unknown what the long term effects may be after a fish has entered into saltwater.

Based on the results of the feed intake experiment, both barged and ROR steelhead fed extremely well after exposure to seawater. Even though there were no differences in feed intake on any given day, the overall feed intake during the experiment was significantly higher in ROR fish than in the barged fish, whether it was calculated using all individuals or using only feeding individuals; however, both groups were feeding well. It is possible that ROR fish were eating more because of in-river migration depleting energy reserves. Fish in both groups appeared to be osmoregulating well based on their plasma sodium, plasma potassium, and muscle moisture levels. Only one mortality in both types of fish occurred during the experiment, suggesting no differences in mortality after 14 days in saltwater.

Timing of yearling steelhead smolt arrival in the estuary may be the most important factor affecting their survival. If smolt arrival in the estuary is timed correctly, a significant amount of mortality may be avoided. The smolts should preferentially arrive at a daily or tidally beneficial time to avoid predation. We observed a relationship between river flow and migration speed for the ROR steelhead. Discharge can be used to increase speed of fish and passage through the estuary for both barged and ROR fish. The timing of barge releases in conjunction with discharge rates, or vise versa, could be used in order to allow smolts to arrive at the estuary at times when terns and cormorants are not feeding (i.e., darkness). Barging itself is probably not directly detrimental to the survival of fish; it is the secondary effects such as timing of barging that may be harmful to the steelhead outmigrants.

Another main factor that was hypothesized as an influence on the survival of steelhead was that the physiological condition would affect survivability. If a fish is not physiologically prepared to enter saltwater, it may behave in such a manner as to make it more vulnerable to avian predators. Better smolted fish prefer saltwater (Iwata, 1995; McInerney, 1964) and will therefore enter this deeper water more quickly, presumably avoiding predation. The hydrodynamics of the estuary may give smolts little choice to avoid saltwater if not prepared to be in it. Thus even if they avoid avian predators, they may be ○flushed○ into saltwater in a condition that does not allow them to survive. The data collected in this field season does not support the hypothesis that condition affects behavior and predation susceptibility. There were differences in condition factor, gill ATPase, and cortisol levels, yet these differences did not effect the migration speed, migration patterns, mortality from piscivorous birds, the preference for saltwater, or the osmoregulation ability in saltwater.

Further research and data analyses need to be completed before specific management recommendations can be made. More work should be done around the timing issues described above, the above descriptions of which are simply possibilities and not specific recommendations. This was the first year describing and assessing steelhead migration in the estuary. Since the migration behavior of juvenile salmonids is influenced by river conditions such as flow (a function of dam discharge) and tidal stage, data should be collected in multiple years to account for annual variability that characterizes the Columbia River system. The saltwater preference and food intake experiments should also be performed in multiple years. A critical area that remains unexplored is at the mouth of the river; we have limited information concerning detailed migration behavior of juvenile steelhead into saltwater. Increased understanding of smolt behavior at the freshwater/saltwater interface, which is miles long, may provide insight on what may be done to minimize rates of avian predation. Another area which should be investigated in more detail is how survival into saltwater ultimately affects returning spawner populations. An existing life-history model for salmonids should be developed and validated for the outmigrating juvenile stage. It can then be used to predict adult populations and effects of management decisions concerning the hydropower system and other areas of concern such as avian predators. Once the relationship between fish quality and behavior, as affected by river and estuary conditions, is understood, the opportunity exists to manage the migration of juvenile salmonids through the Columbia Basin hydropower system in such a way that their subsequent survival is maximized.

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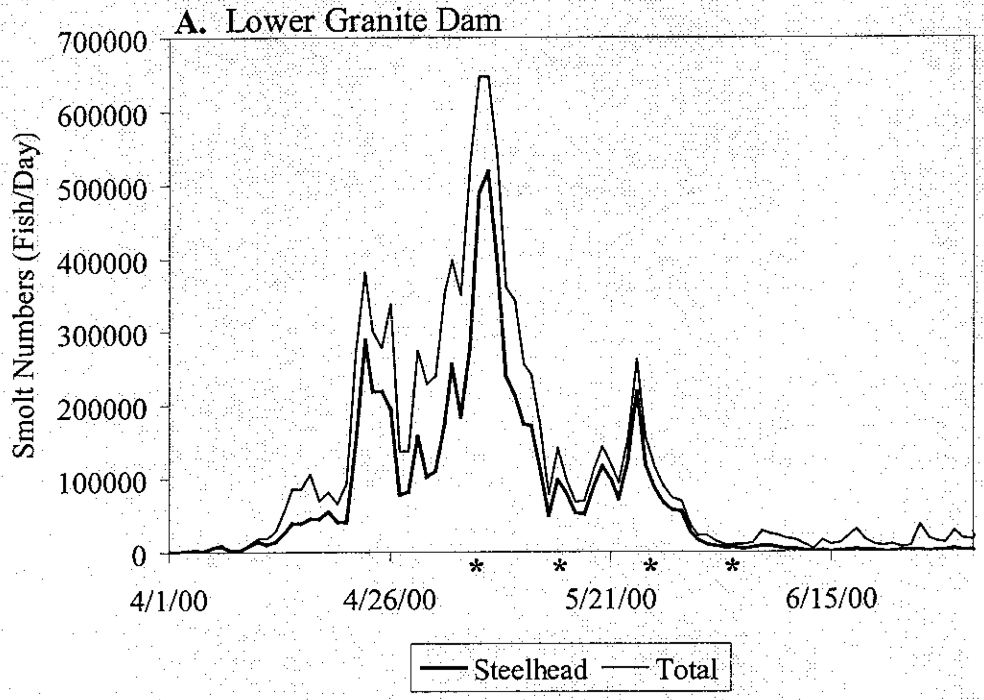
Table 1. Summary of fish used during the 2000 field season. Numbers, length, and weight of fish used for radio-tracking, physiological sampling, saltwater preference experiments (SWP), and the feed intake experiment are given for each release of fish. Mean and range (in parenthesis) are given for lengths and weights. For fish numbers, entries with "+" indicate: standard+depth tags for tagging or numbers in replicate groups for saltwater preference experiments.

Sampling Type	Fish Type	Sampling Date							
		5/1/00	5/2/00	5/4/00	5/5/00	5/15/00	5/24/00	5/25/00	6/4/00
# of Tagged Fish Released	Barged				16+2	18+2		18+2	18+2
	ROR				18+2	18+2		18+2	4+1
# of Physiology Fish	Barged				10	10		10	
	ROR				6	10		10	
# of SWP Fish	Barged			7+7			7+7		
	ROR			7+7			7+7		
# of Feed Intake Fish	Barged		50						
	ROR	18	30						
Length of Tagged Fish Released (mm)	Barged				227 (196-260)	227 (202-275)		236 (200-280)	225 (160-269)
	ROR				217 (175-290)	241 (202-297)		227 (194-267)	240 (231-248)
Length of Physiology Fish (mm)	Barged				228 (209-248)	235 (202-275)		243 (220-260)	
	ROR				232 (220-245)	243 (210-270)		232 (205-262)	
Length of SWP Fish (mm)	Barged			215 (169-243)			233 (204-270)		
	ROR			215 (183-247)			231 (201-255)		
Length of Feed Intake Fish (mm)	Barged		215 (169-243)						
	ROR	215 (183-247)	215 (183-247)						
Weight of Tagged Fish Released (g)	Barged				107.0 (60-169)	102.0 (72-178)		109.6 (59-188)	99.7 (37-167)
	ROR				89.7 (43-214)	109.2 (73-156)		94.1 (54-144)	103.0 (90-117)
Weight of Physiology Fish (g)	Barged				108.7 (89-132)	113.0 (68-154)		121.4 (89-151)	
	ROR				112.0 (93-129)	115.8 (70-169)		105.5 (68-156)	
Weight of SWP Fish (g)	Barged			88.6 (42-125)			106.9 (64-182)		
	ROR	85.6 (52-131)		85.6 (52-131)			99.5 (67-152)		
Weight of Feed Intake Fish (g)	Barged		88.6 (42-125)						
	ROR		85.6 (52-131)						

Table 2. Fish depth and depth of water where fish were found. The "Water Depth" column for the fixed monitoring station shows the maximum possible depth in the area, while the boat and plane data show a known depth near the fish. Data in italics are questionable. Fish depth was converted from tag pulse rates.

Release #	Group	Date	Time	Water Depth (m)	Fish Number	Fish Depth (m)
1	Exit	5/7/00	11:34	22.9 max	148.772	3.2
1	Exit	5/7/00	12:33	22.9 max	148.862	4.3
2	Exit	5/17/00	7:21	22.9 max	148.894	1.2
2	Exit	5/17/00	9:43	22.9 max	148.983	2.4
2	Exit	5/18/00	1:59	22.9 max	148.953	2.4
3	Exit	5/27/00	13:55	22.9 max	148.833	5.8
3	Exit	5/27/00	15:08	22.9 max	148.771	3.9
3	Exit	5/27/00		22.9 max	148.771	2.8
3	Exit	5/28/00	1:40	22.9 max	148.802	8.7
4	Exit	6/6/00	13:53	22.9 max	148.863	3.8
2	*Plane*	*5/17/00*	*12:31*	*12.5*	*148.712*	*-38.2*
2	*Plane*	*5/18/00*	*9:21*	*14.9*	*148.983*	*35.7*
2	*Plane*	*5/18/00*	*9:40*	*2.7*	*148.712*	*82.6*
3	*Plane*	*5/28/00*	*9:55*	*2.1*	*148.833*	*50.4*
3	*Plane*	*5/28/00*	*10:12*	*22.3*	*148.802*	*31.2*
2	Boat	5/18/00	4:44	16.8	148.983	1.7
2	Boat	5/18/00	5:15	18.0	148.983	1.7
2	Boat	5/18/00	5:44	12.2	148.983	1.9
2	Boat	5/18/00	7:02	1.5	148.983	2.8
2	Boat	5/18/00	7:17	5.8	148.983	2.8
2	Boat	5/18/00	7:41	11.3	148.983	2.8
2	Boat	5/18/00	8:00	5.5	148.983	2.8
2	Boat	5/18/00	8:23	8.5	148.983	3.2
2	Boat	5/18/00	8:52	24.1	148.983	2.9
2	Boat	5/18/00	9:30	13.1	148.983	4.5
2	Boat	5/18/00	9:51	7.0	148.983	3.9
2	Boat	5/18/00	10:21	10.4	148.983	3.9
2	Boat	5/18/00	11:09	16.2	148.983	3.5

Figure 1. Daily collections of (A) juvenile salmonids at Lower Granite Dam and (B) steelhead at Bonneville Dam. Dates on which barged and ROR steelhead were collected for radio-tagging are indicated by asterisks (*). Smolt numbers were obtained on the internet at http://www.cqs.washington.edu/dart/pass_com.html, courtesy of the Fish Passage Center.



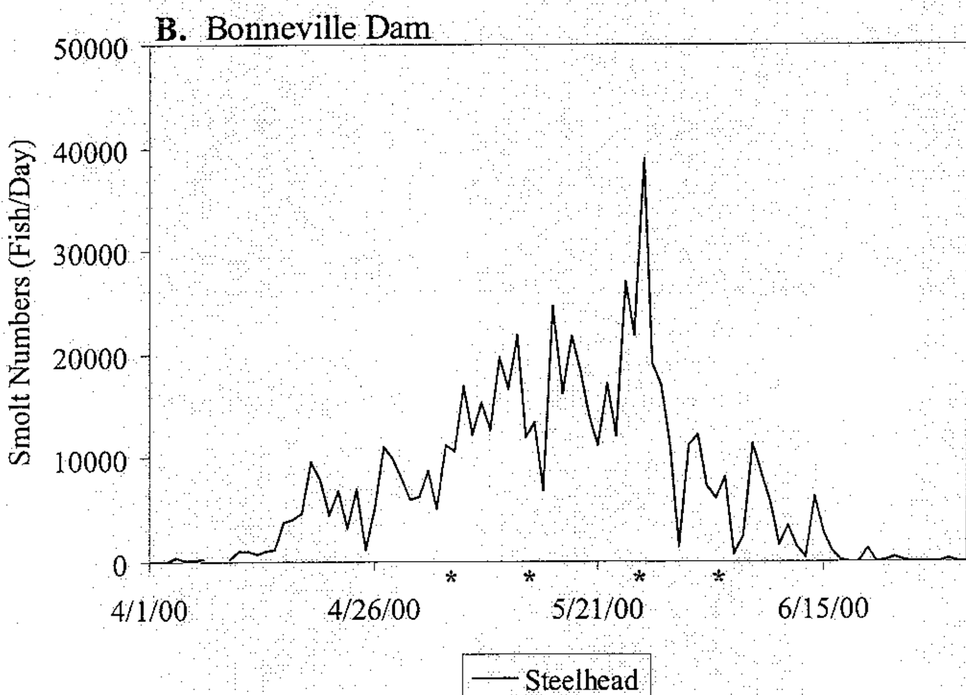


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Figure 2. The distance traveled downstream over time for the barged (top set) and ROR (bottom set) steelhead for each release during the 2000 season. The fish with the "+" as markers were eventually eaten by piscivorous birds in the estuary. The distance was calculated from the fixed monitoring station, boat, and plane data points.

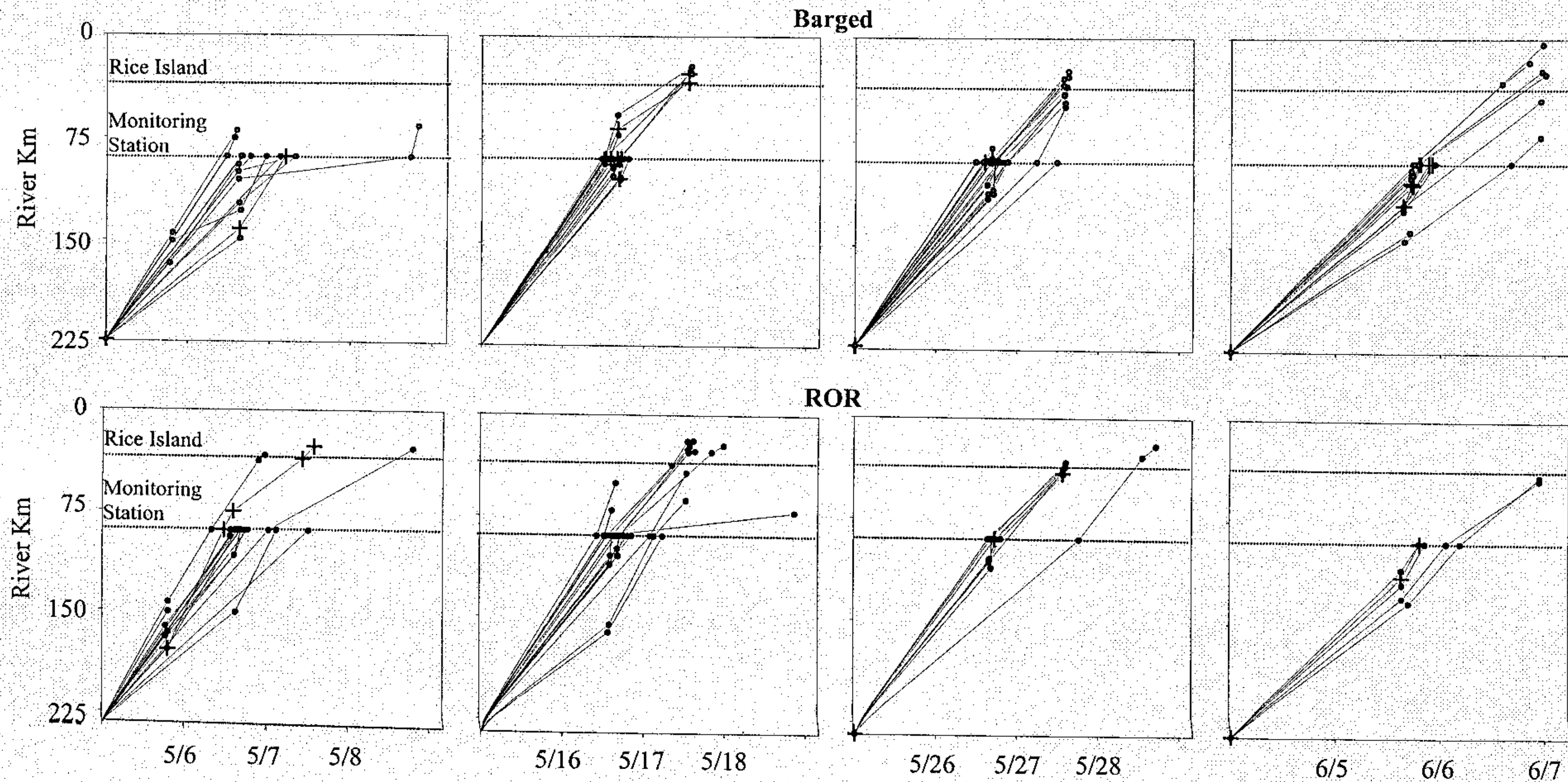

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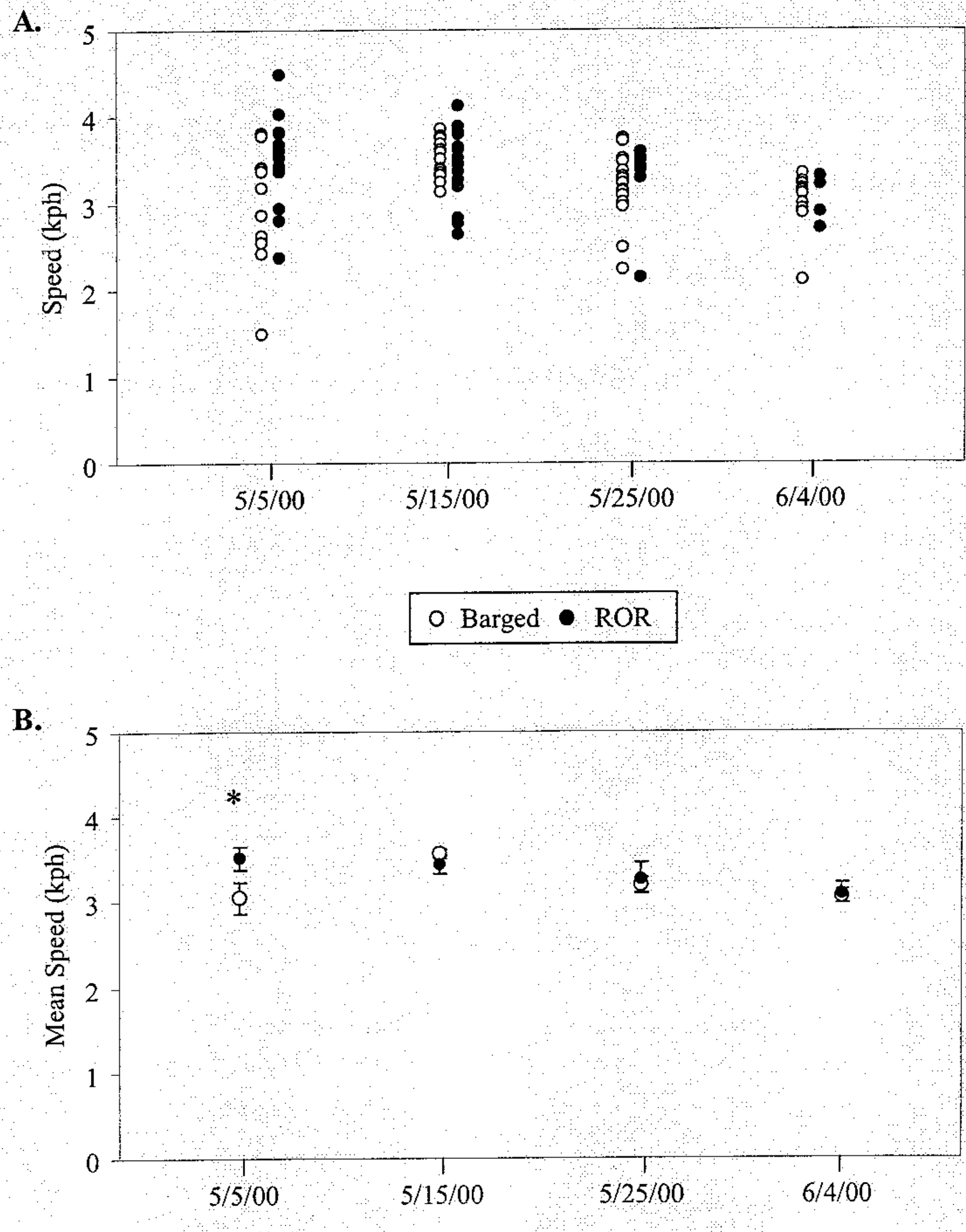
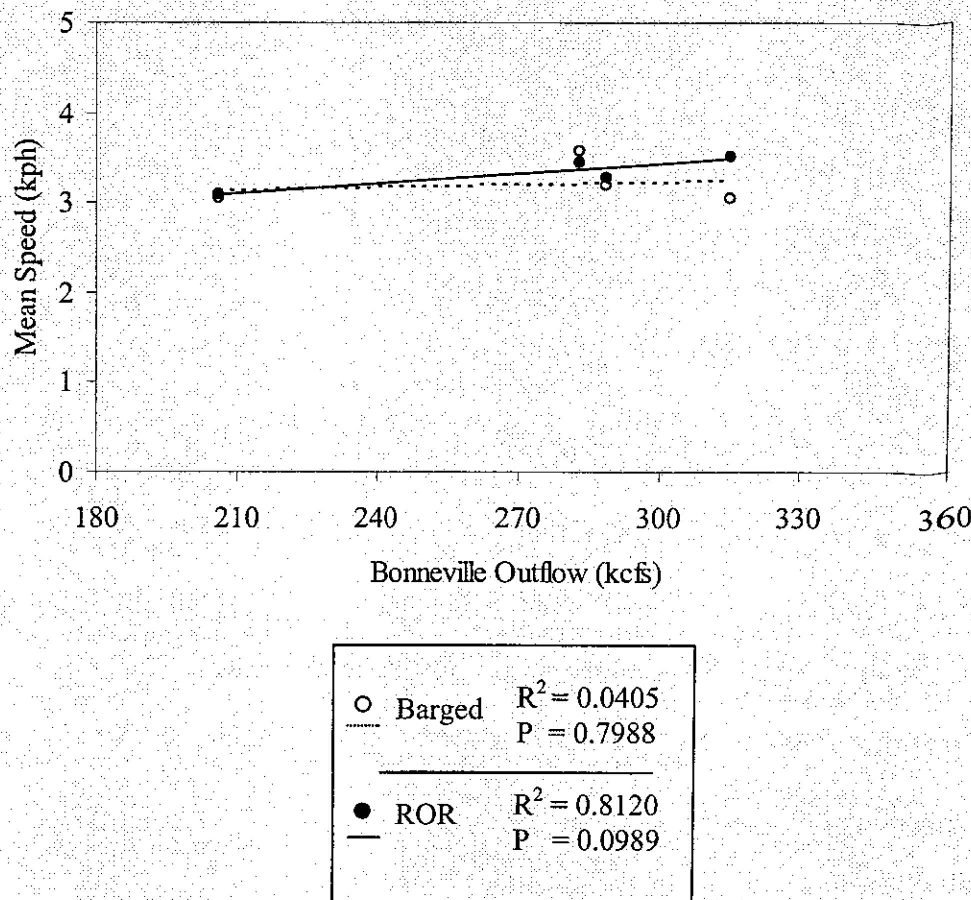
Figure 3. (A) Migration speed in kilometers per hour (kph) of all fish and (B) mean speed (± SE) for each release of radio-tagged barged and ROR steelhead measured from the release site to a monitoring station near the upstream end of the Columbia River Estuary. Significant differences between types within a date are indicated with asterisks (*), other statistical differences are described in the *Results* section.



C29244

Figure 4. Correlation between mean migration speed (kph) and mean outflow on the release date from Bonneville Dam. Barged and ROR steelhead are indicated with regression lines and statistics. Flow data were obtained from the Army Corps of Engineers internet site at http://www.nwd-wc.usace.army.mil/cgi-bin/dataquery.



C29245

Figure 5. (A) The mean length (± SE) and (B) condition factor (± SE) of the radio-tagged barged and ROR steelhead. Significant differences between types within a date are indicated with asterisks (*), other statistical differences are described in the *Results* section.

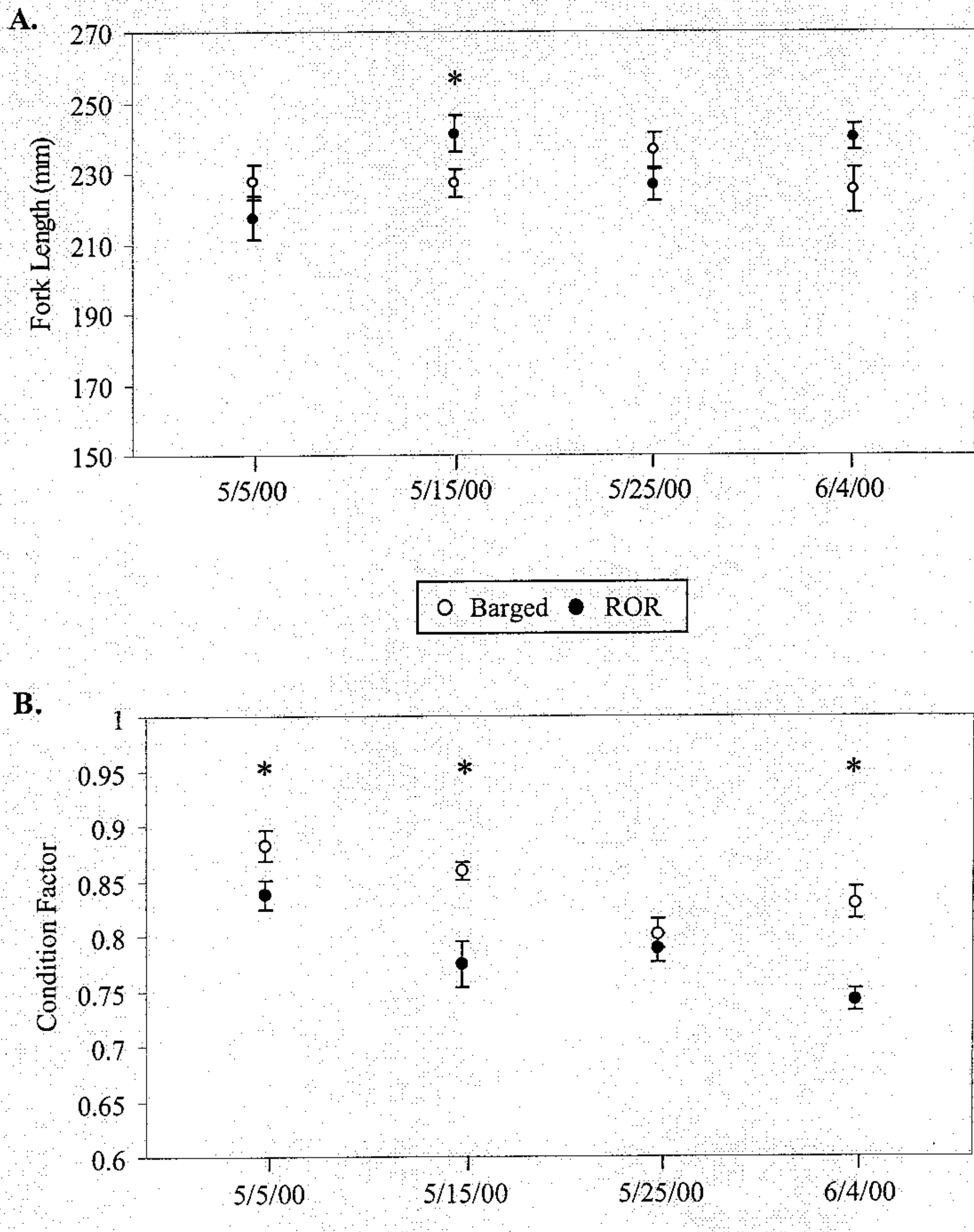
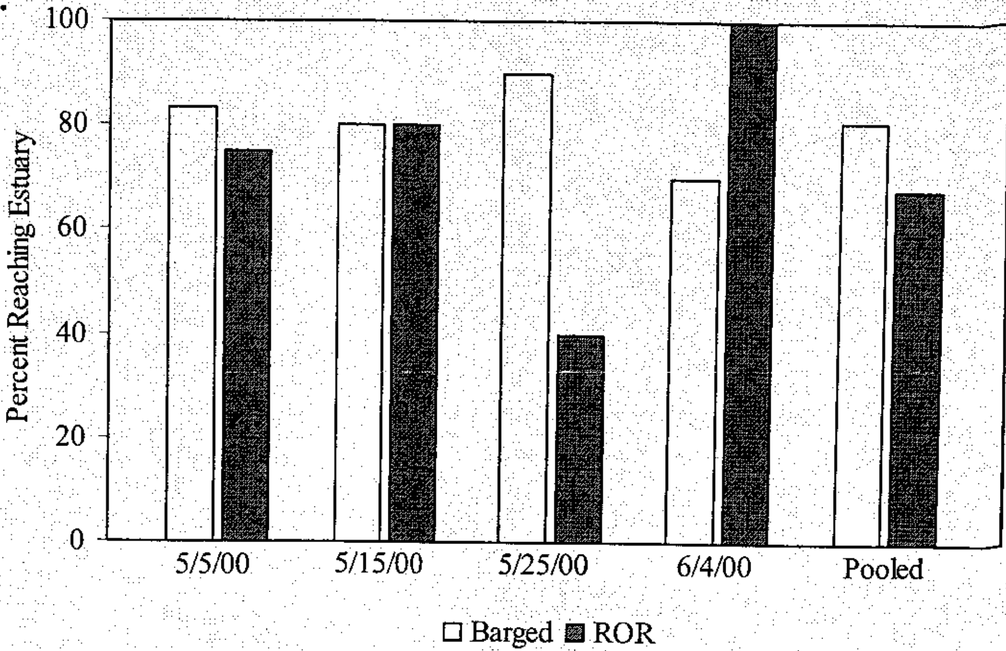
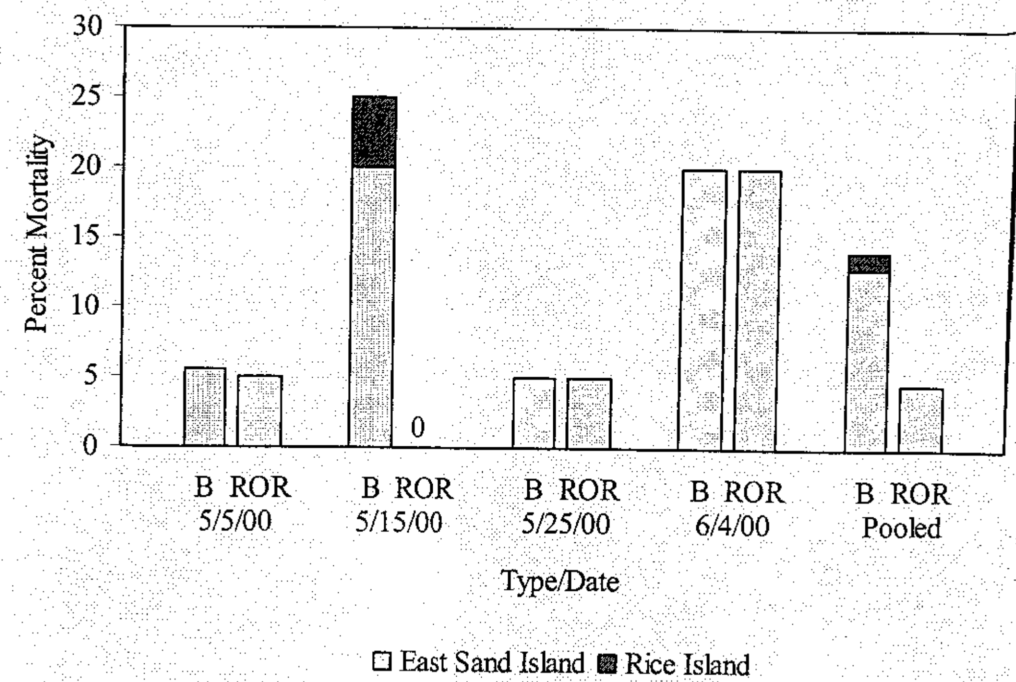


Figure 6. (A) The percentage of radio-tagged fish reaching the estuary and (B) the percentage of mortality from piscivorous birds on Rice and East Sand Island.

A.

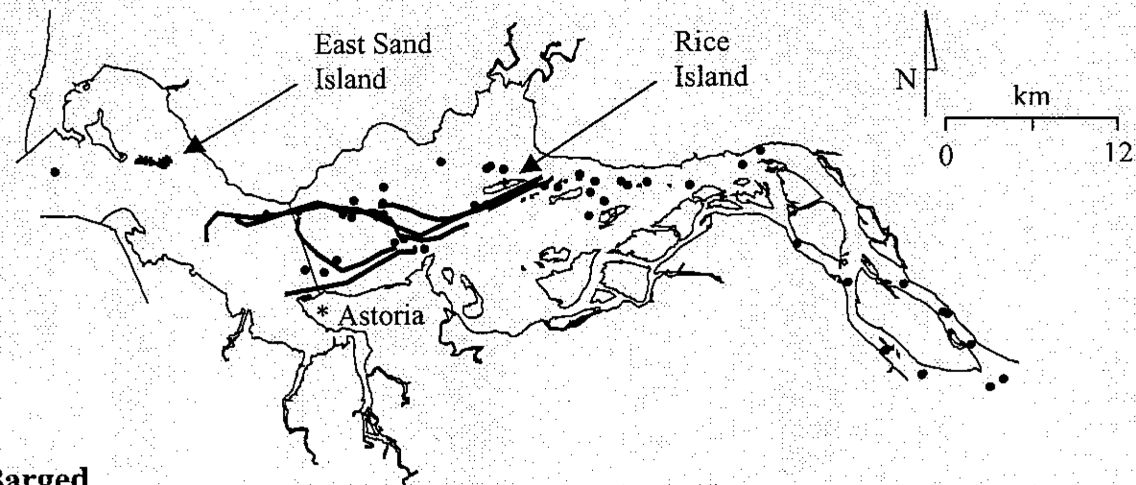




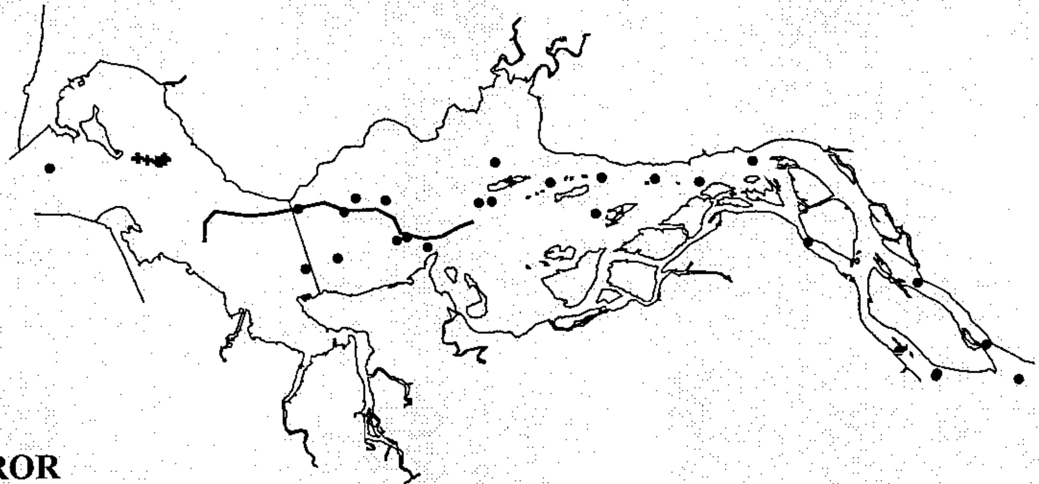
C29247

Figure 7. All data collected in the estuary for (A) barged and ROR fish combined, (B) barged fish, and (C) ROR fish. Dots represent data collected from aircraft, lines are data obtained by boat tracking, and "+" markers on islands represent mortalities from piscivorous birds.

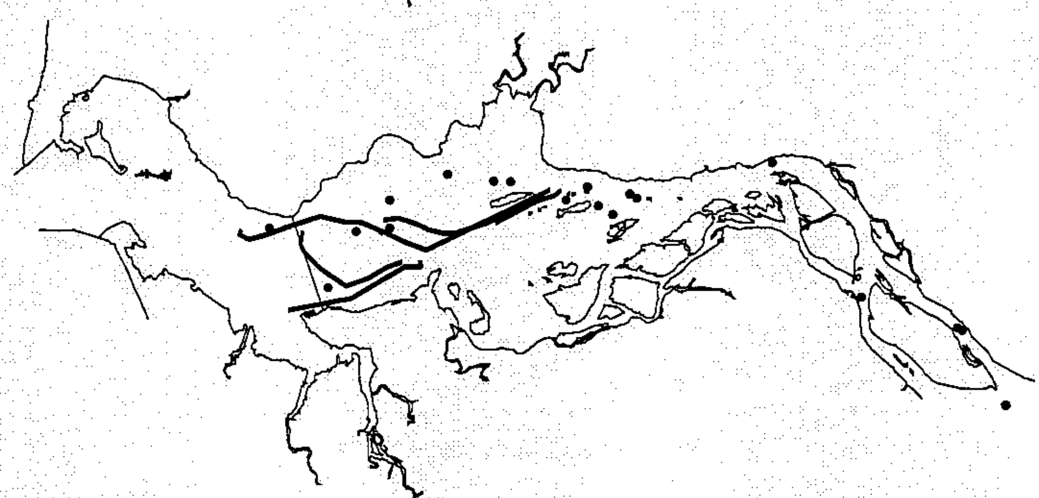
A.



B. Barged



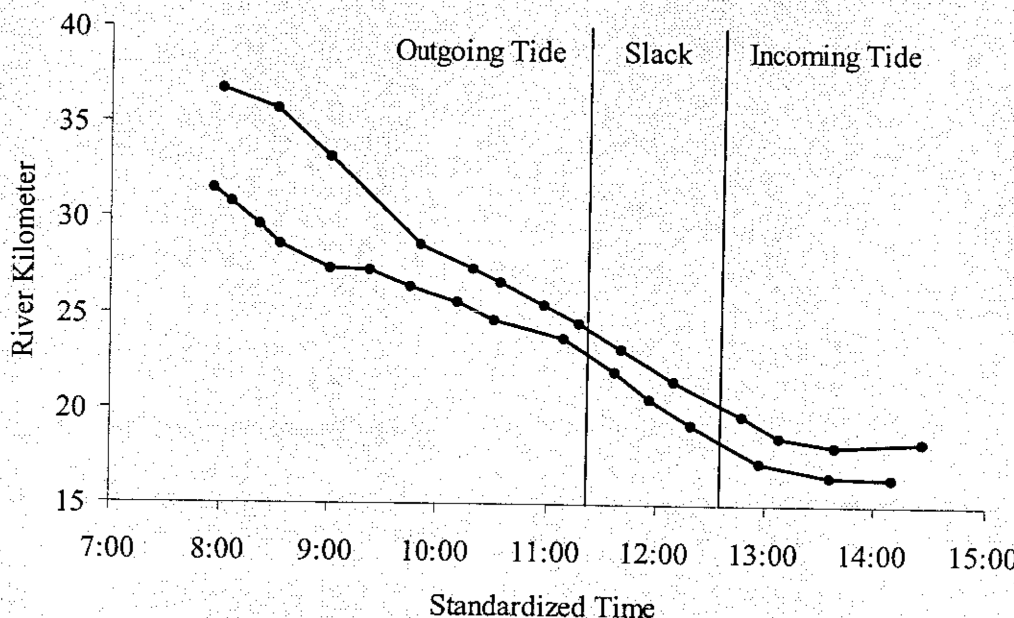
C. ROR



C29248

Figure 8. (A) Migration speed in relation to the tide of two steelhead tracked by boat in the estuary. (B) Average speed of all tracked fish in the estuary during different tidal stages, error bars show the range of speeds. Significant differences are described in the results section.

A.



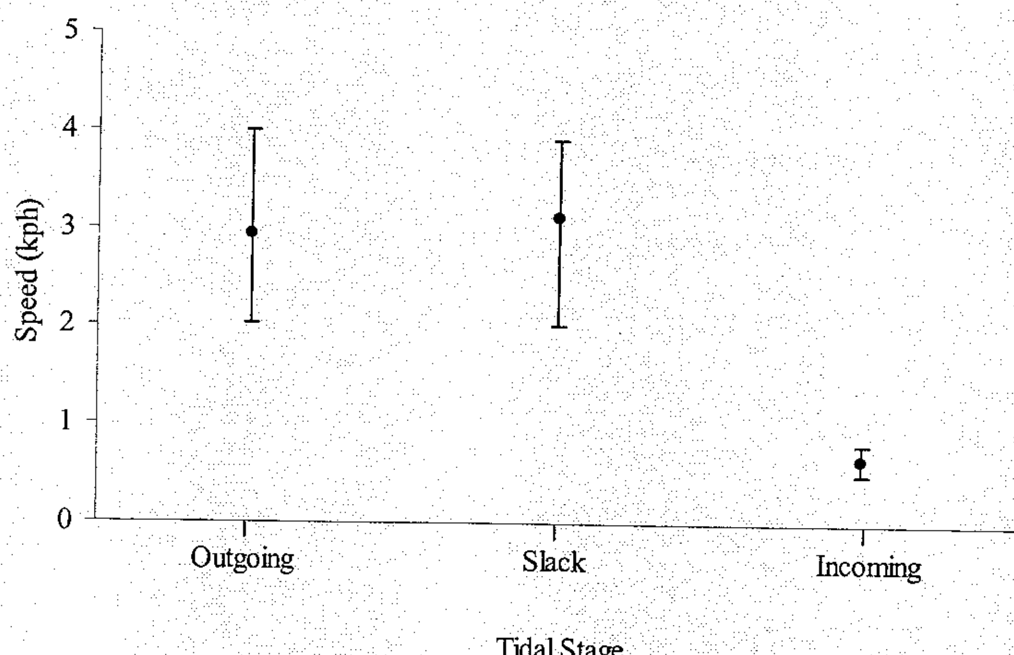


Figure 9. The depth of a fish while being tracked by boat in the estuary. See results section for figure details.

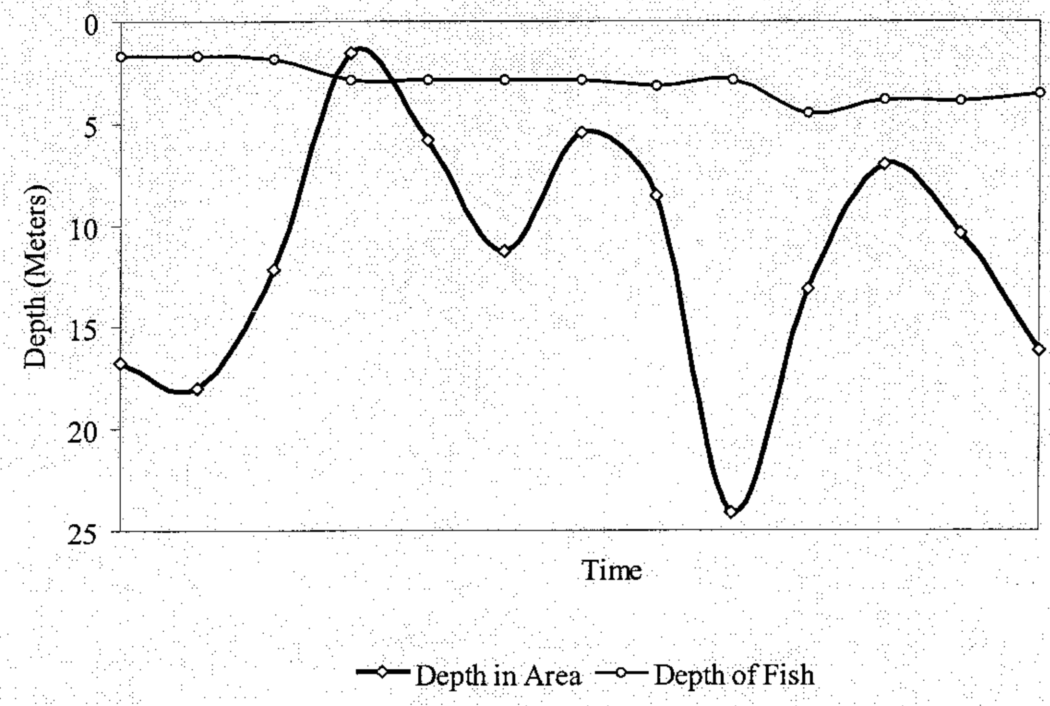
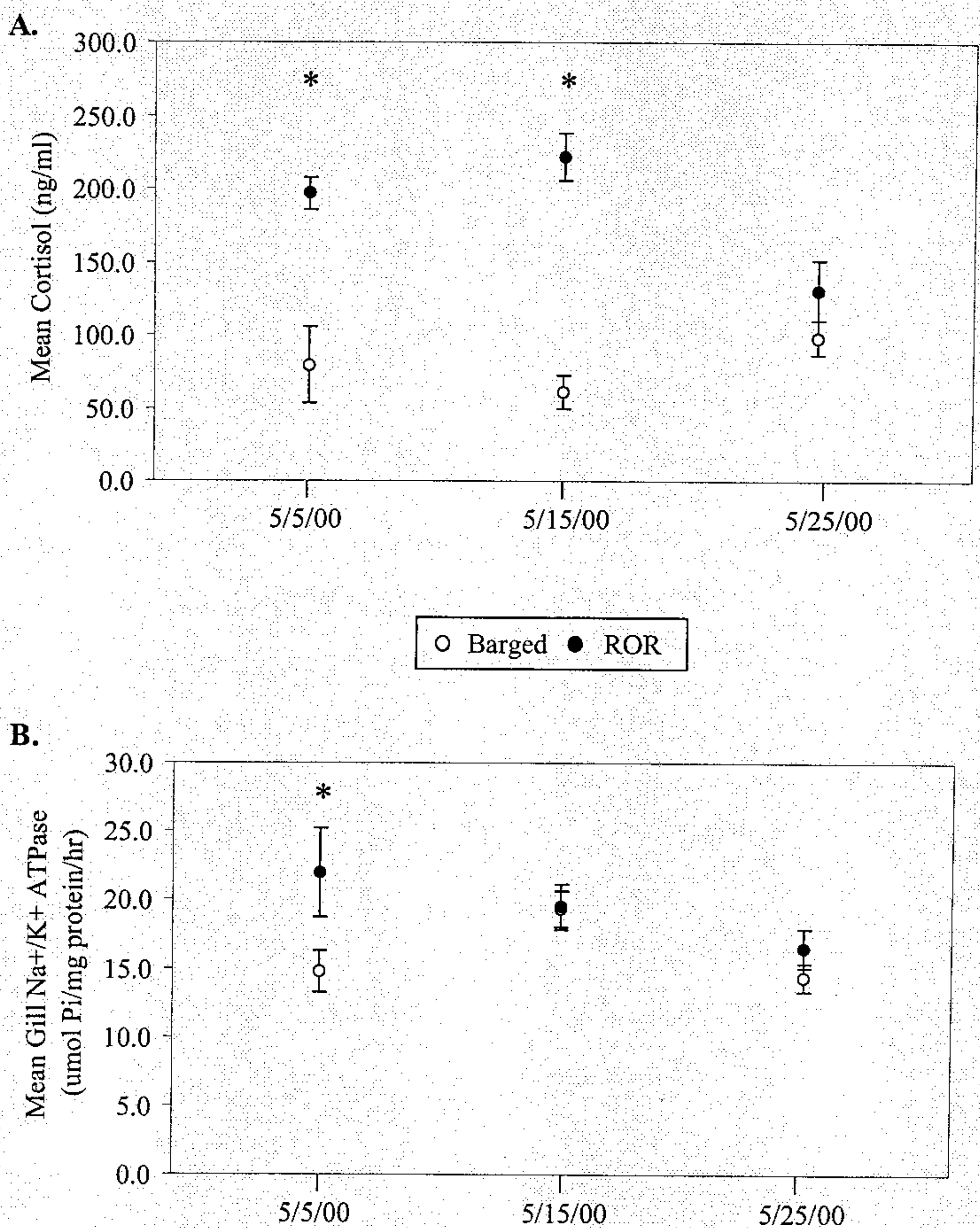
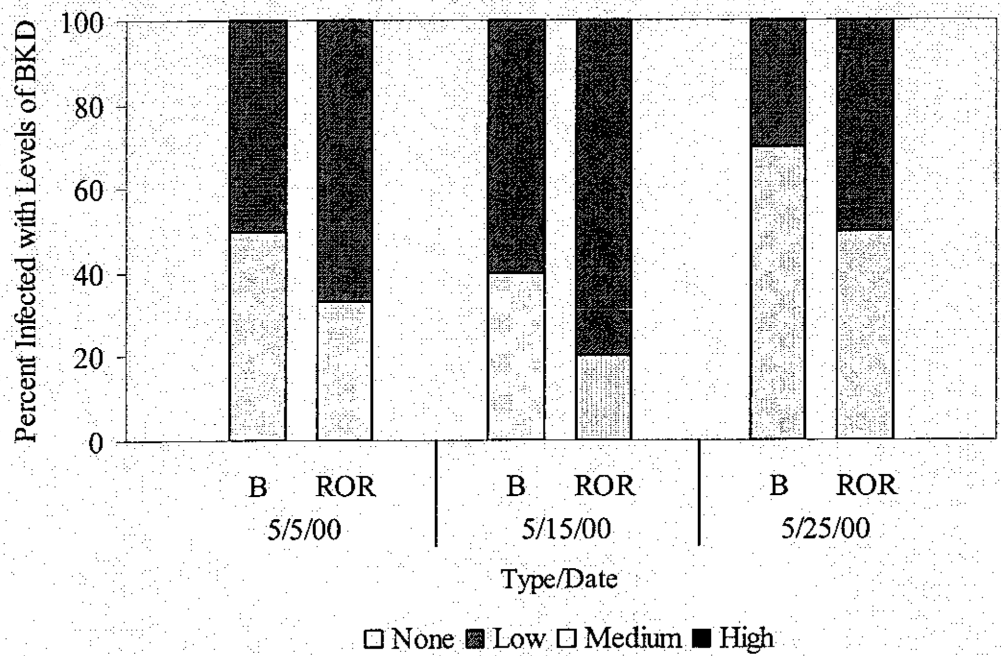


Figure 10. (A) Mean plasma cortisol levels (± SE) and (B) mean gill Na^+/K^+ ATPase activity (± SE) of the barged and ROR steelhead. Significant differences between types within a date are indicated with asterisks (*), other statistical differences are described in the *Results* section.



C29251

Figure 11. The percent of fish infected with certain levels of Bacterial Kidney Disease (BKD) in barged and ROR steelhead. Significant differences are described in the *Results* section.



C29252

Figure 12. (A) The percent of fish in saltwater after 60 minutes during the saltwater preference experiment and (B) those in saltwater after 120 minutes. Error bars indicate ±SE between replicate tanks. Significant differences are described in the *Results* section.

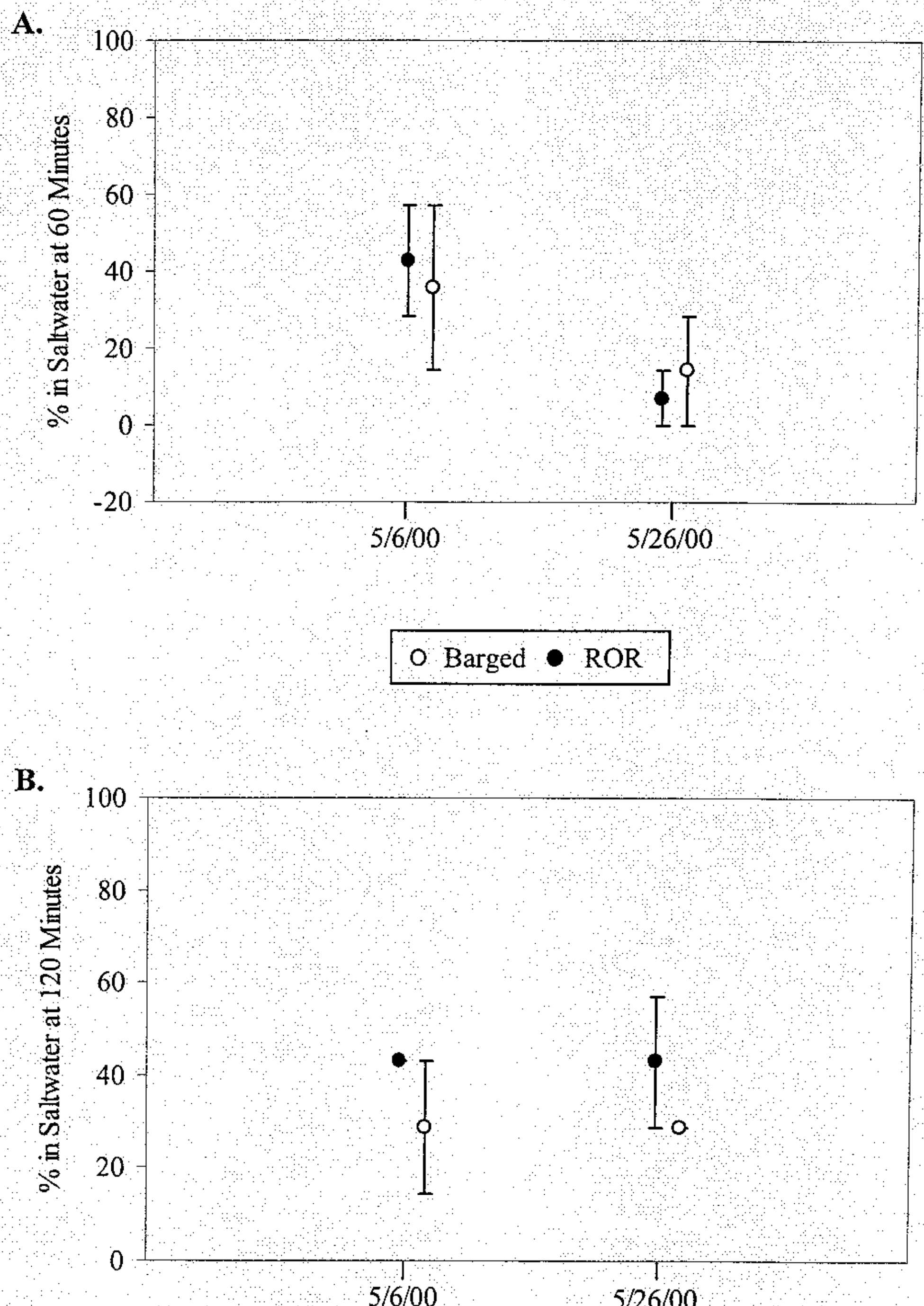


Figure 13. (A) Mean weight (± SE) and (B) condition factor (± SE) of barged and ROR steelhead in the feed intake experiment. Significant differences between types within a date are indicated with asterisks (*), other statistical differences are described in the *Results* section.

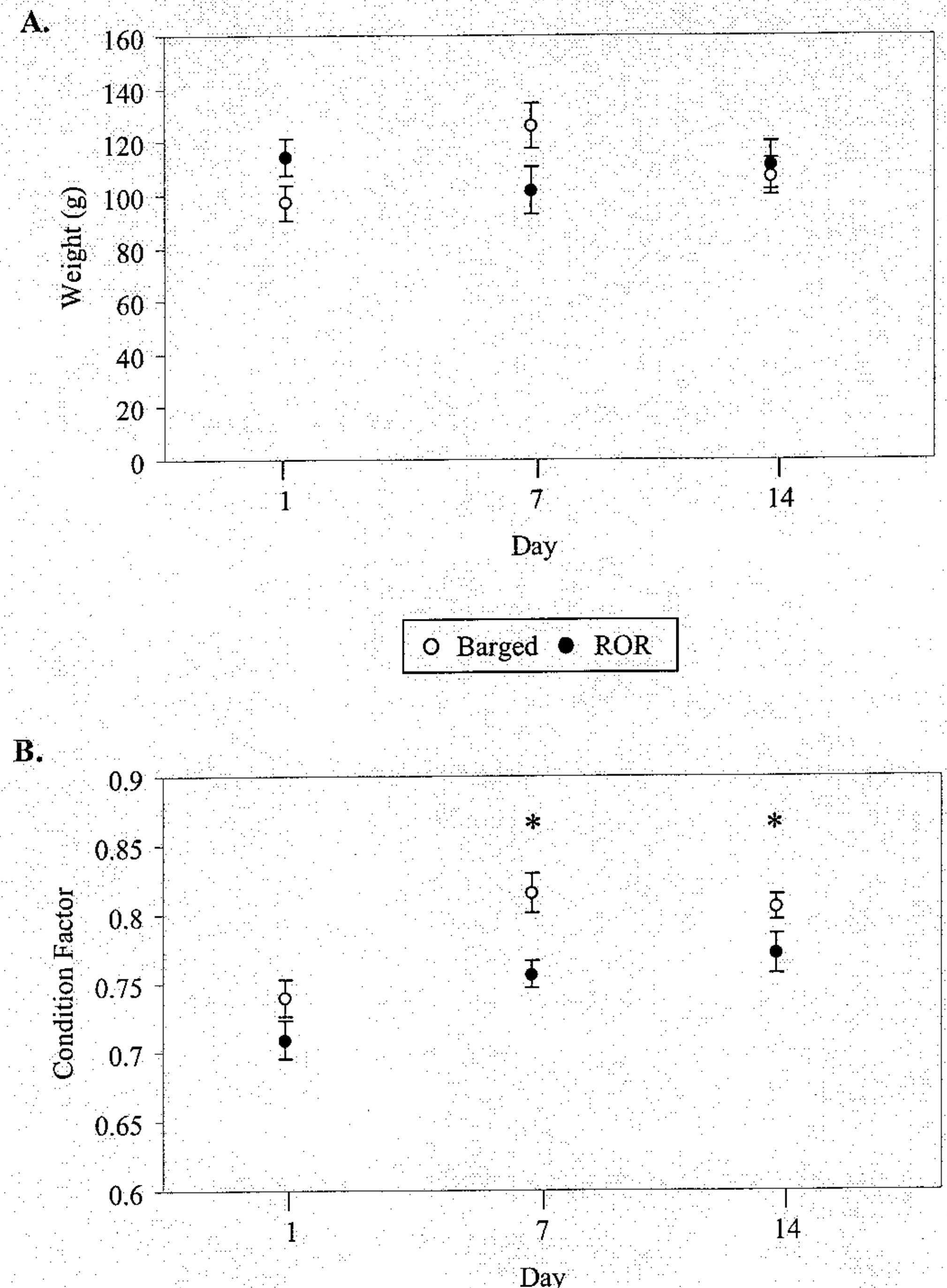
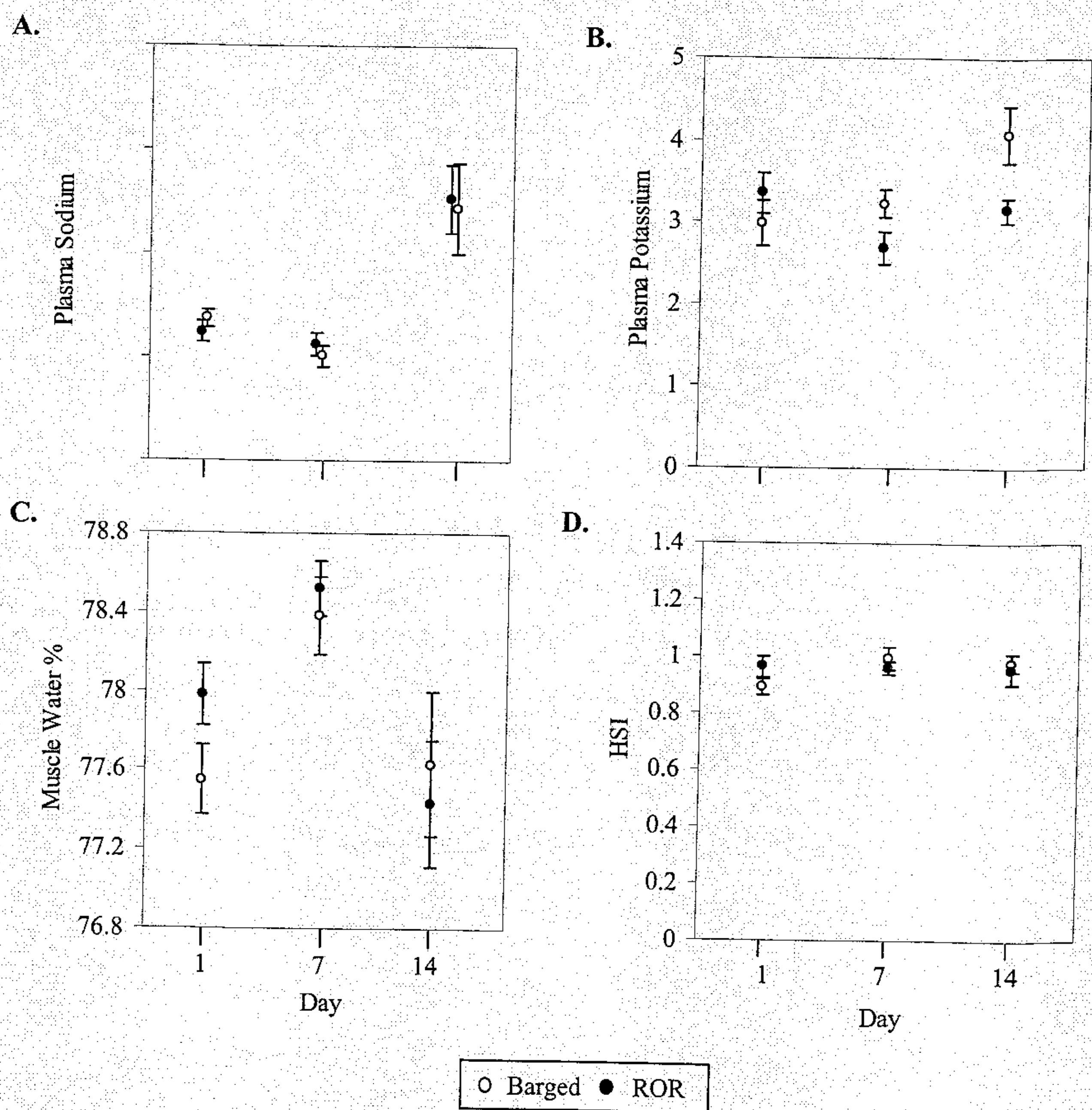


Figure 14. Mean (± SE) (A) plasma sodium, mmol/l, (B) plasma potassium, mmol/l, (C) muscle moisture level, and (D) hepatosomatic index (HSI) of the barged and ROR steelhead in the feed intake experiment. Significant differences are described in the *Results* section.



C29255

Figure 15. Mean feed intake (% of body weight; ± SE) values of barged and ROR steelhead in the feed intake experiment. Significant differences are described in the *Results* section.